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THE AMOUNTS OF MOISTURE EMITTED FROM THE EYES AND PERIORBITAL AREAS

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THE AMOUNTS OF MOISTURE EMITTED FROM THE EYES AND PERIORBITAL AREAS

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ABSTRACT

Experiments were carried out to determine the amount of moisture emitted by the eyes and the periorbital areas under various conditions of temperature, humidity and activity. Under ambient laboratory conditions the rate of moisture emission from the eyes varied between 0.3 and 1.5 g/h.

RÉSUMÉ

Des expériences visant à determiner la quantité de vapeur d'eau dégagée par les yeux et les régions périorbitaires ont été effectuées dans diverses conditions de température, d'humidité et d'activité. Sous les conditions de température ambiente en laboratoire, on a constaté que les yeux dégagaient de 0.3 à 1.5 g/h de vapeur d'eau.

INTRODUCTION

This work was undertaken as support for a project on the design of a head protection system which would prevent the deposition of fog or frost on spectacles or goggles under Arctic winter conditions. A requirement arose for data on the amount of water vapour emitted from the eyes and the periorbital areas since it was thought that the amount of water vapour coming from the eyeballs, which are always moist, would contribute significantly to the fogging of spectacle lenses.

A search in the literature for data did not disclose any information on this point, and a series of experiments were carried out to determine the amounts of water vapour emitted from the eye area of a person wearing goggles. The effects of several variables were investigated, including work rate and reduction of the effects of the eyeball by keeping the eyes closed. Experiments were performed in the laboratory during each season of the year and data presented in this report refer to ambient laboratory conditions.

EXPERIMENTAL

Equipment and procedures

The goggles used in these experiments were plastic and shaped to fit closely around the eyes, forehead and cheeks. The approximate area covered by the goggles was 86 cm^2. For the purposes of these experiments the periorbital areas were defined as those areas of the face covered by the goggles.

Each side of the goggles was fitted with a small tube for attachment to a rubber hose. Room air was drawn through one hose and then through

the goggles across the eye region where it picked up moisture from the eyes and the periorbital areas. The flow rate of air was controlled by an Edwards needle valve and measured with a Fisher flowmeter of range up to 2180 ml/min. The water-vapour in the air was absorbed by four drying tubes of the usual chemical U-tube type, arranged in series on a board (Figure 1). The drying tubes were weighed before and after each experiment with the stopcocks closed to determine the weight of moisture absorbed.

The air was drawn from the outlet port of the goggles, via hoses, through the four drying tubes in series, then in turn through the flowmeter and the metering valve. All hose connections and stopcocks were carefully checked to ensure against leaks.

An effort was made to secure as good a seal as possible between the perimeter of the goggles and the subject's face. It was felt that small leakages, if they occurred, would not cause serious difficulties. Any such leakage would be inwards and no moisture would be lost before being absorbed by the drying agent in the tubes. A hose was attached to the inlet port of the goggles and allowed to hang near the floor to avoid drawing in the subject's breath.

Preliminary tests were carried out to select an appropriate drying agent for use in the study. A commercial desiccant (Drierite), consisting of calcium sulfate anhydrite containing a small quantity of a moisture-sensitive indicator compound, was chosen for use in all subsequent experiments. This desiccant, when dry, is coloured blue and changes to pink when nearly saturated with water. In all these experiments, the colour change due to moisture absorption in the desiccant occurred progressively in the first tube, and no colour change appeared in the second tube until the first was almost completely changed. The third and fourth tubes did not change appreciably in weight or colour.

Initial experiments were performed under conditions of low humidity (13% - 18%). Air was drawn through the four drying tubes for an hour at a time at a flow rate of 10.1 litres per hour. The weight of moisture collected was compared with that calculated to exist in the air, knowing the temperature, relative humidity and pressure. The formula used for calculation is given in Appendix 1. The anhydrite when tested under these conditions did not absorb all of the moisture calculated to exist in the air which was passed through the drying tubes.

Two distinct effects were noted upon raising the flow rate. The first was a substantial improvement in the apparent efficiency of the desiccant in removing moisture from laboratory air. The second was an increase in the amount of moisture collected from the eye area.

The flow rate was raised in increments of about 15 litres per hour from the original 10.1 litres per hour. It was considered desirable to select a flow rate which would be high enough to deliver a maximum amount of the eye area moisture to the drying tubes and yet not be so high as to cause watering of the eyes. It was found that when the flow rate reached 102 litres per hour, the subject began to just perceive the passage of air over the eyes. There was no significant difference between the amount of moisture collected

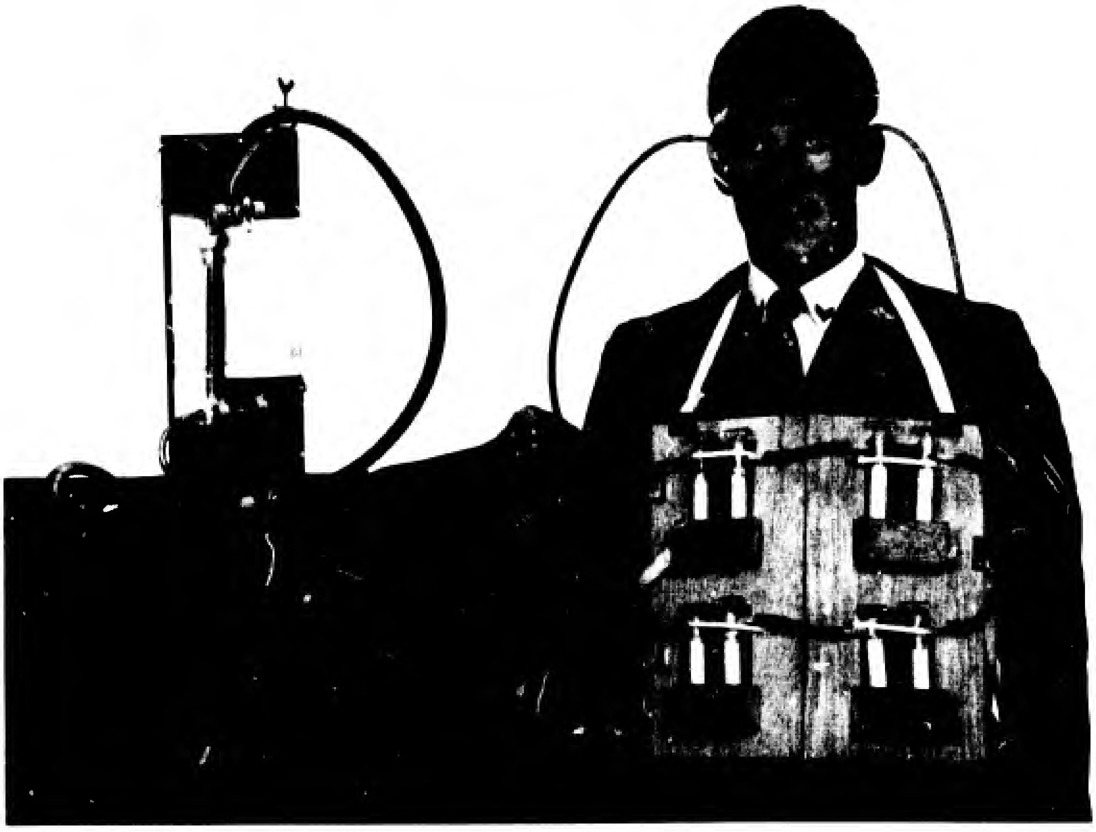

Fig. 1 Experimental set-up for determining amount of water vapour emitted from eyes and periorbital areas.

at this rate and the amount collected at the next lower rate (86.5 litres per hour). This was an indication that the maximum amount of eye area moisture available was being collected and the flow rate of 102 litres per hour was selected for use in all subsequent experiments. The efficiency of the anhydrite at the increased flow rate in removing moisture from laboratory air at different relative humidities is shown graphically in Figure 2.

Determination of moisture emitted from the eye area

No attempt was made to control the ambient conditions during experiments, but careful records were kept of prevailing conditions i.e. temperature, relative humidity and atmospheric pressure. Either before or after each experiment with a live subject, a control experiment was done in which the amount of moisture present in the laboratory air was measured and compared with the amount of moisture collected in the drying tubes. The percentage of the calculated moisture actually collected was considered as the efficiency of the desiccant under the given conditions.

Thus, the corrected total weight W of moisture collected from the eye area of the subject was determined by the formula $W = (B - A)/x$ where

A = weight of moisture absorbed from laboratory air during the control experiment,

B = total weight of moisture absorbed during experiment with the subject, and

x = efficiency of the desiccant at the prevailing humidity. Above 35% RH, x varied little and had an average value of 0.95.

Many of the experiments were conducted with the subject at rest, sitting in a chair for the duration of the experiment. It was also considered desirable to obtain some results under working conditions. For this purpose, a specific work load was imposed on the subject. A weight of 9 kg (20 lb.) was repeatedly lifted from the floor to a height of one metre. This was done at varying rates, the most common rate being 180 lifts during a period of one hour. The weight was lifted at five minute intervals. In the case of 180 lifts per hour, the weight was lifted 15 times every five minutes.

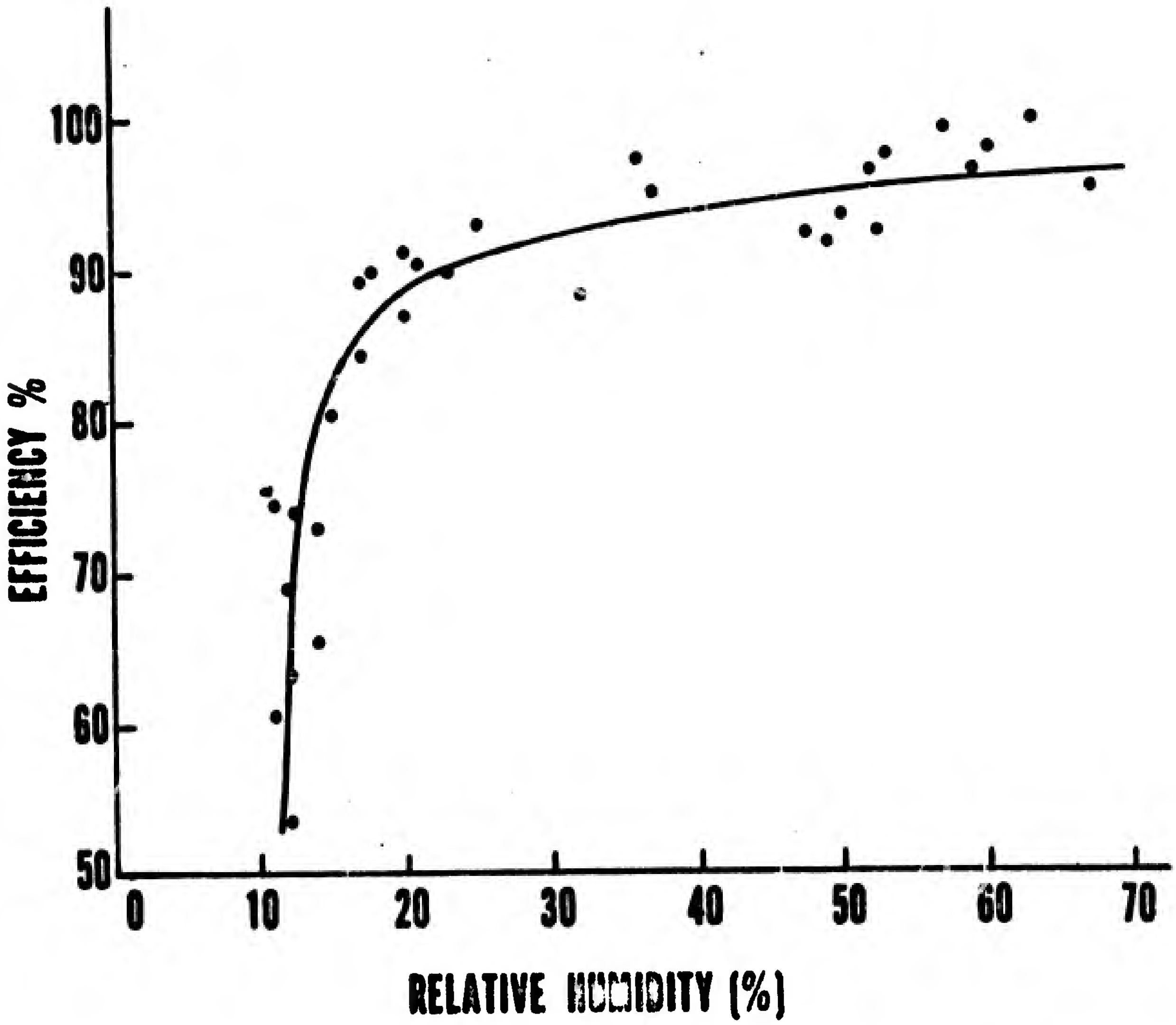

*Fig. 2: Efficiency of $CaSO_4$ anhydrite in removing water-vapour from an air flow.
Flow rate = 102 l/hr*

RESULTS

In experiments of this nature, a great many variables are encountered such as temperature, humidity, work rate and other more subtle physiological and psychological factors which may affect a subject's sweating rate. It was not considered feasible to investigate the effects of each of these variables while keeping the others constant, as the number of experiments required would be prohibitive. It was decided, rather, to acquire a reasonable number of results throughout a range of atmospheric conditions normally found in the laboratory and for a limited range of work loads. Four subjects were employed during the experiments.

It became evident, as was expected, that both temperature and humidity had marked effects on the amount of moisture produced. It was considered desirable to have an index number (thermal index) which would indicate the thermal stress produced by the combined effects of these two factors. A modified form of the wet-bulb globe temperature (WBGT) index of thermal stress described by Yaglou and Minard in 1956 (Ref. 1) was used. The usual WBGT formula is as follows:

WBGT = 0.7 wet-bulb + 0.2 globe thermometer + 0.1 dry-bulb temperature.

This WBGT index was intended for use in outdoor situations where radiant heat load was a significant factor. Since the experiments described here were conducted indoors, the formula was modified to:

Index = 0.7 wet-bulb + 0.3 dry-bulb temperature.

It was found that the amounts of water vapour collected from the air during control experiments varied with the ambient thermal index in the manner shown in Figure 3. This correlation indicates the procedure used is sufficiently sensitive to show the effects of small differences in the thermal index.

Table I shows the rate at which water vapour was collected from the eyes and periorbital areas of subjects at rest at the average thermal index for the experiments.

FIGURE 3

RELATIONSHIP BETWEEN THERMAL INDEX AND RATE OF MOISTURE COLLECTION DURING CONTROL EXPERIMENTS

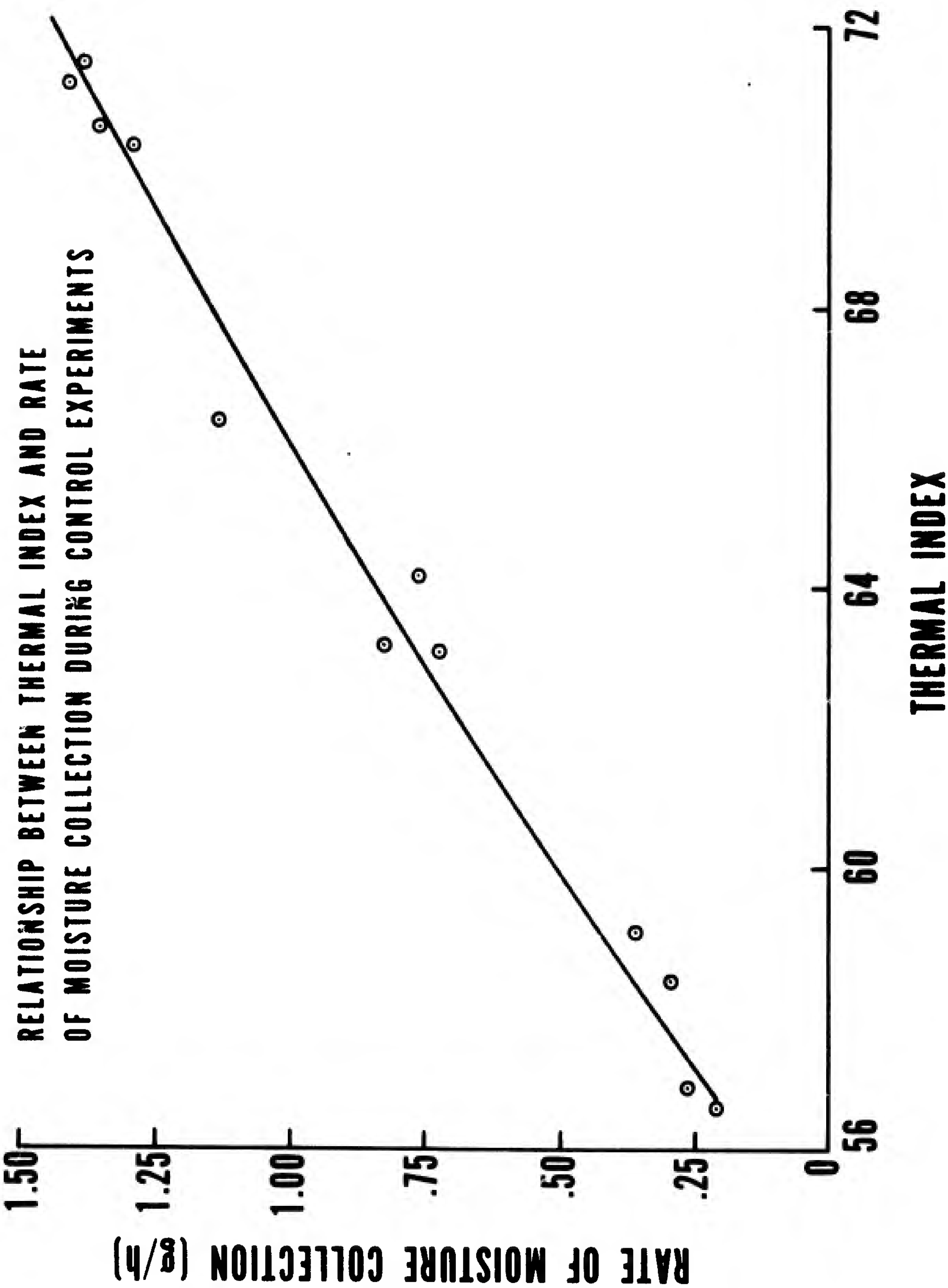

TABLE I

Collection Rate of Water Vapour Emitted from the Eyes and Periorbital Areas for Subjects at Rest

Subject	No. of experiments	Thermal Index (avg.)	Average Rate of Water Vapour Collection From Eyes and Periorbital Areas (g/h)	Range of Values (g/h)
C	10	56.9	0.476	0.372 - 0.612
D	14	58.4	0.520	0.344 - 0.679
A	8	63.1	0.418	0.294 - 0.469
C	10	63.2	0.388	0.319 - 0.528
B	10	70.3	0.776	0.420 - 1.23
C	5	71.2	0.639	0.343 - 1.06

The maximum variation of any thermal index within a group is ±5.0 from the average index.

For comparison, Table II shows the rate at which water vapour was collected from the eyes and periorbital areas of subjects performing work. The TEST MODE in this table refers to the number of times per hour that the subject lifted a 9 kg weight to a height of one metre.

TABLE II

Collection Rate of Water Vapour Emitted From the Eyes and Periorbital Areas of Subjects Performing Work

Subject	No. of experiments	Test Mode	Work Rate (Nm/h)	Thermal Index (avg.)	Average Rate of Water Vapour Collection From Eyes and Periorbital area (g/h)	Range of Values (g/h)
C	7	120	10,560	66.2	0.726	0.440 - 0.992
C	7	180	15,840	56.6	0.569	0.492 - 0.634
D	9	"	"	59.1	0.691	0.401 - 1.10
A	5	"	"	70.6	1.02	0.483 - 1.44
B	10	"	"	71.5	1.00	0.506 - 1.30
A	8	360	31,680	64.2	0.721	0.374 - 1.05

It was a matter of interest to determine the effect of closing the eyes on the amount of moisture collected. A series of 16 experiments was done during half of which the subjects kept their eyes closed. The results are shown in Table III.

TABLE III

Effect of Closing the Eyes

Subject	Eyes Open		Eyes Closed	
	Thermal index	Rate of Water Vapour Collected (g/h)	Thermal index	Rate of Water Vapour Collected (g/h)
C	56.3	.456	56.4	.612
C	57.4	.433	57.8	.427
D	56.8	.487	54.0	.501
D	57.1	.528	57.3	.482
D	59.1	.325	58.5	.438
D	60.5	.679	58.7	.630
D	64.9	1.109	64.7	.327
D	71.0	.901	70.4	1.228
Avg.	60.4	.615	59.7	.581

Scatter of these results is too great to allow any conclusion to be drawn about the effect of closing the eyes.

DISCUSSION AND CONCLUSIONS

In physiological experiments of this type the main difficulty is caused by the subject's variability. This shows in the considerable scatter of results for any one subject.

Higher ambient temperatures, as expected, cause more sweating and in some experiments moisture condensed on the upper parts of the goggles. This was absorbed in filter paper and weighed but was found to be only a few milligrams, and negligible compared with the total weight collected. This small loss was therefore ignored.

Unlike control experiments with laboratory air, the water vapour collected from subjects does not show a definite relationship with the thermal index, presumably because other factors, not identified, have an important influence. The rate of air-flow over the eyes was chosen arbitrarily as that which effected the maximum collection of water-vapour. Obviously, the flow rate will determine to some extent the amount of moisture emitted from the eye area. In practical cases of men wearing spectacles and/or goggles in the field, the air flow may vary widely, and its effect on moisture emissions will vary accordingly. Hence the emissions actually found must be regarded as being near the maximum amounts which might be expected.

Since moisture from the subjects' breath was excluded from these measurements, the figures given in the last column of Tables I and II indicate roughly the amounts of water vapour which might condense on the inside of goggles worn by soldiers under Arctic winter conditions. For subjects at rest, the amounts of moisture produced are not markedly different from the amounts of moisture present in the ambient air at a given thermal index and are only slightly higher than ambient for subjects performing work. Thus, the contribution to spectacle frosting under winter conditions by moisture emitted from the eyes and periorbital areas is probably insignificant compared to the amount of frosting caused by moisture in the breath.

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APPENDIX

Method of calculation of moisture content of air

Consider a volume of air, V litres, at atmospheric pressure B mm mercury and dry bulb temperature T°C. If the partial pressure of water vapour in the air is e

$$e = E_W - 0.00066B(T - T_W)\ (1 + 0.00115\ T_W)$$

where E_W is the vapour pressure of water at T_W°, the wet bulb temperature. Also the volume of the water vapour constituent of the air is $\frac{e}{B}$ V and therefore the dry air volume present is $(V - \frac{eV}{B})$. To obtain the mass of water vapour present, tables of the density of moist air (D_M) and the density of dry air (D_D) can be used. Then: Mass of water vapour

$$= VD_M - (V - \frac{eV}{B})\ D_D$$

$$= V(D_M - D_D + \frac{D_D e}{B})$$

All necessary data can be obtained from Tables in Ref. 2.